ADAPTABILITY OF FILM BADGE DOSIMETRY FOR LOW LEVEL GAMMA RADIATION

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

There exist two methods of radiation dosimetry readily adaptable for personal monitoring purposes. One method utilizes electroscopes of such dimensions that portability in the pocket or on the clothing of the person involved is possible. The second method utilizes the reaction caused in certain film emulsions upon exposure to gamma radiation. The result of the reaction is an increase in the density of the film. This increment in density can be measured and equated to a specific quantity of radiation.

I. THE PROBLEM

Statment of the problem. The purpose of this study was to determine if Kodak Personal Monitoring Film, Type 2, is applicable for personal gamma dosimetry under the conditions of radioactive exposure normally encountered in the nuclear physics laboratory at Drake University.

Justification of the problem. The United States Atomic Energy Commission requires that certain maximum quantities of radiation received personally shall not be exceeded in a given time. To conform to these requirements necessitates the use of dosimetry devices. The reliability of the

Kodak film must be determined before it is used in conjunction with or replaces the present method of dosimetry.

The main factors determining reliability of the film method of dosimetry involve the reproducibility and sensitivity of the film. The level of radiation used in the nuclear physics laboratory at Drake University is low. Kodak reports the Type 2 film has a minimum sensitivity of twenty milli-roetgens. This is more than is anticipated to be encountered in laboratory work at Drake. If the sensitivity of the film is such that it will give accurate recordings at the level of radiation normally encountered in the situation under study, Drake University could employ this film as a dosimetry device. The reproducibility of the film must also be ascertained.

Limitations of the problem. The investigation will be limited in scope to factors encountered at Drake University in the nuclear physics laboratory. The film badges will not be exposed to radiation exceeding the highest amount a student would at a maximum receive for one week's time. Since the radioactive source available in the laboratory is used in such a manner that the student does not receive more radiation than is necessary, no matter how small the quantity, there is no necessity for investigating the characteristics of the film at elevated levels. If Drake at a later date adopts the Kodak film, investigation at the higher levels would be advisable as a precaution in the event of an incident occurring in the use of the radioactive material.

The effects on optical density caused by changes in developer temperature and concentration when varied from Kodak's recommended conditions will be investigated only within the maximum lower and upper range of changes that might be expected to be encountered in the darkroom operation. The investigation of these variables will not be an attempt to give correction factors adaptable to correcting optical density measurements of films processed at a later date under conditions varying from those recommended by Kodak. The investigation will endeavor only to determine if the variables tend to affect this particular film and if to such an extent that the variables will have to be controlled in darkroom procedures. The effect of development time will not be considered in the investigation since time may be accurately determined to within a few seconds using equipment available.

II. DEFINITIONS OF TERMS USED

Film badge. Kodak Personal Monitoring Film, Type 2.

Developing tank. Throughout the report of this investigation, the term "developing tank" shall be interpreted as meaning a container in which film may be placed while in a dark room and then sealed light-tight. The sealing shall be of a nature permitting the addition and removal of liquid chemicals.

Developer. The term shall be interpreted as referring to Kodak Dental X-ray Developer of the liquid form. Unless otherwise stated, it shall have been mixed at a temperature of twenty degrees centigrade in the ratio of 404 cc. of water to 96 cc. of concentrated solution as produced by the manufacturer.

Fixer. The term shall refer to Kodak Dental X-ray Fixer of the liquid form. It shall have in all instances been mixed at a temperature of twenty degrees centigrade in the ratio of 404 cc. of water to 96 cc. of the concentrated solution as produced by the manufacturer.

Emulsion number. The term shall be interpreted as meaning the code number applied to each batch of Kodak Personal Monitoring Film, Type 2, by the manufacturer.

Density. The term defined as the Optical Density or logarithm to the base ten of the light intensity incident

(I_0) on the film divided by the light intensity (I) transmitted by the film.

__Net density__. The term shall be interpreted as meaning the numerical value obtained upon subtraction of the optical density value of a film exposed to no radiation due to experimentation from the optical density value obtained of a film subjected to experimental exposure to radiation.

__Source__. The term shall be interpreted as referring to the 5.3 milli-curie Cobalt-60 capsule available in the nuclear physics laboratory at Drake University. The serial number of the capsule is 340.

__Remote control device__. The term refers to the mechanical equipment utilized by the investigator in the study to permit remote withdrawal and insertion of the radioactive capsule in respect to the storage container.

__Code number__. The term refers to a reference number applied to each sample of film used in the investigation.

__Densitometer__. The term shall refer to the Weston Phtographic Analyzer Model 877, of serial number 1291, manufactured by the Weston Electric Instrument Corporation of Newark, New Jersey, and available in the Drake University physics department.

Standard conditions. The term shall refer to the development process utilized in the investigation. The developer shall have been mixed at a ratio of 96 cc. of concentrated solution as produced by the manufacturer to 404 cc. of water. The development process shall have been carried out at a temperature of twenty degrees centigrade for a period of five minutes. The fixer shall have been mixed in the same proportions as the developer and the films shall have remained in the fixing solution for a period of ten minutes.

III. LITERATURE REVIEW

A large amount of material has been written concerning the use of film with radioactivity of varying types and amounts. Much of this literature has been concerned with the use of films as a personal dosimetry device. A brief summary of the works which relate to the situation under study will be given.

Baumgartner conducted a recent analysis of the Kodak Type 2 film under the conditions of use encountered at the

Hanford Atomic Products Operation.[1] The investigation had three objectives; (1) to determine film characteristics to different types, energies, and amounts of radiation; (2) to determine the influence of changing developing conditions in the darkroom; and (3) to determine image fading characteristics of the film upon storage following exposure and preceding development. The first investigative object is of little value to the problem under study since it involves radiation having differing characteristics as stated and the radiation at the institution in which the investigation was conducted is of one type.

Baumgartner investigated three aspects involved in development: (1) time; (2) temperature; and (3) position of the film in the solution, since no agitation was used. Twenty eight sets of calibrated films, ranging from 0 to 5,000 milli-roentgens of radium gamma radiation, were developed for seven different times ranging from two to eight minutes and four temperatures ranging from 66 degrees fahrenheit to 74.2 degrees fahrenheit.

The results indicated the increment in optical density

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[1] W. V. Baumgartner, Investigation of Kodak Personal Monitoring Film Type 2 for Potential Use at H. A. P. O., (Richland: General Electric Company, 1958), 17 pp.

due to developer temperature increases to be linear over the temperature range studied. The gradient was found to be 0.10 ± 0.04 optical density per degree with 95 per cent confidence. The developer time gradient was likewise found to be linear during the interval two to six minutes. The gradient in this case was found to be 0.12 ± 0.06 optical density per minute with 95 per cent confidence. Also it was determined that time, temperature, and calibration level interact positively, resulting in accelerated development of the films, especially those calibrated at high levels.

To determine image fading characteristics, Baumgartner exposed films to doses of radium gamma radiation of 100, 200, 600, 800, 1000, and 5000 milli-roentgens. Film samples were held for three, two and one months, two and one weeks, and one day following exposure and prior to development. The resulting data indicated an increase in density of approximately twelve per cent for a three month period. Additionally, data indicated the increment in density to the three month period to be an essentially linear function.

There are several similarities in the factors investigated by Baumgartner and the investigation conducted at Drake University. The fact that Baumgartner's work deals with levels of radiation, which in their lowest quantities are significantly greater than the maximum levels encountered in the situation under investigation, limits its applicable value to Drake. The report did, however, indicate some of the factors which must be considered and some of the procedural methods upon which a film dosimetry service may be built. Differences in facilities at the two laboratories necessarily dictate different data obtaining methods and darkroom procedures.

G. M. Corney, in a summary article concerning some of the basic characteristics of film in general, lists several factors applicable to the situation under investigation.[1]

Corney states that any film is sensitive to gamma radiation. The resulting density upon exposure to radiation is dependent on (1) variation in sensitivity of the films with quality of exposing radiation, and (2) processing procedures.

Corney specifically emphasizes that many errors can be avoided by developing a control film with the exposed film where applicalbe, rather than relying on periodic checks of the film inventory by developing samples taken from it.

A major error in processing can occur when the

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[1]G. M. Corney, "Relation of Film Characteristics to X- and Gamma-ray Monitoring," Nucleonics, X (November, 1952), p. 84.

developer becomes exhausted. Corney states the effects of exhaustion depend on the average density of the developed film, carry-out of developer by processed film, and the manner in which loss of developer is replaced.

IV. ORGANIZATION OF THE INVESTIGATE REPORT

The remainder of this report will involve a description of the experimental techniques employed in the data collection process. The actual data collection for each of the segments of the investigation will be dealt with separately and an analysis of the data made. The results of the data will be included in the text in graphical form.

CHAPTER II

EXPERIMENTAL TECHNIQUE

There are several pieces of equipment and a number of techniques peculiar to this investigation. This chapter will deal with the equipment used in the investigation and the procedures developed for using the equipment.

I. EQUIPMENT INVOLVED

The equipment necessary for the investigation falls into two catagories; (1) that used in the nuclear laboratory; and (2) that used in the darkroom.

The radioactive source employed for the investigation was the serial number 340 calibrated Cobalt-60 source available in the physics department of Drake University. The source is a 5.3 milli-curie gamma source calibrated at 7.2 milli-roentgens of gamma radiation per hour at one meter on September 8, 1959. The source is encapsuled in a small cylinder mounted on the end of a threaded screw and nut arrangement. When not in use it is stored within a lead cylinder to render it safe for movement within the laboratory under proper procedures. The container is threaded so the screw and nut assembly to which the radioactive capsule is attached may be firmly fastened into it for storage of the source, and may be unscrewed to permit the withdrawal of the radioactive material. The nut of the screw and nut assembly is provided so that a long rod may be afixed to the assembly, thus permitting the source to be manipulated from a distance.

A remote control device to permit withdrawal and replacement of the source from its container was employed. This is in keeping with the obligation under which the laboratory is operated of not permitting more radiation than is necessary, even though it remains far below the maximum permissible dosage. The device consisted of a ring stand to which is clamped a rod to be screwed into the nut of the screw and nut assembly. A cord attached to the rod was passed through a curved section of metal tubing, thus enabling a horizontal pull on the cord to result in a vertical movement of the rod, and the consequent removal of the source. The length of the cord was approximately two meters.

A number of cork stoppers were used to hold the film badges while being exposed. A slot was sawed in the tops of the corks, thus permitting the film badges to be wedged in the slot. The slots were sawed at a slight angle with respect to the vertical axis of the corks, thus enabling the film badges to be adjusted approximately perpendicular to the line of sight from the source.

The film badges employed in the investigation were Kodak Personal Monitoring Film, Type 2. The dimensions of the film badges were 1-1/4 by 1-5/8 inches. The films are contained in a light-tight paper container consisting of three parts; (1) the outer, directly visible covering of paper; (2) an inner piece of black paper folded so as to cover both sides of the film, one end of which is cut to form a tab to facilitate removal of the film from the container; and (3) an inner piece of black paper laying directly against one surface of the film.

The outer covering consists on one side of a matte finished white paper. The edges of this paper are folded around the film on all four sides and a smooth sheet of white paper cemented over them. Through this smooth paper the tab from the inner folded paper is brought out. Pulling the tab causes a tearing of the outer cover and additional pulling will remove the film and folded paper from the packet. The design is such that the removal of the film from the packet in totally dark conditions is readily accomplished. An indentation in one corner of the film serves as a position indicator if such is necessary.

The film is classed by Eastman Kodak Company as a wide range film to be used for the purpose of personal dosimetry. It is a double emulsion film in that there is a photographic emulsion on each side of the film base. These are readily identifiable by texture. The glossy side of the film contains an emulsion which responds slowly to gamma radiation. The matte side contains an emulsion which responds rapidly to the same type of radiation. Normally, both emulsions are used since all that is needed is a total optical density measurement. However, in cases where excessive radiation has been recorded, and the resulting optical density is beyond the range of the densitometer, the fast emulsion may be removed with the aid of Farmer's Reducer. The slower and therefore less optically dense emulsion will remain and yield a density measurement which again is within the range of the densitometer. The emulsion removing process is of no importance in this investigation due to the low levels of radiation employed.

Two Landsverk electroscope dosimeters were worn by the investigator as personal dosimetry devices.

Other accessory equipment included a portable lead shield, radiation warning signs, clamps, meter sticks, and a stop watch. The equipment utilized in the darkroom consisted of one model 2, F-R film developing tank, one fifty cubic centimeter graduated cylinder, one centigrade thermometer, developer and fixer solutions, and several glass containers for temporary chemical storage. The tank used permitted the film to be loaded in darkness and the subsequent development processes to be carried out in normal room light. The tank was so constructed as to facilitate continuous agitation of the contents.

II. METHOD OF PROCEDURE

The procedural methods may be divided into three divisions; (1) preparations prior to exposing the film badges to the gamma source; (2) exposing the film badges to the gamma radiation; and (3) development of the exposed film badges and subsequent density measurements.

Upon entry of the investigator into the laboratory, the personal dosimeter (s) to be used were unlocked and the position of the indicating hairline on the scale determined. If more than ten milli-roentgens of radiation were indicated as having been received by the dosimeter, it was recharged using the charging apparatus as furnished by the manufacturer. The reading of the dosimeter at that time was recorded in the log of the laboratory as the starting reading on that date. Approximately one-half way through the investigation, the investigator began wearing two dosimeters after a slight discrepency was noted between the reading of the one dosimeter then worn and the estimated quantity of radiation received for that day based on time and distances of the investigator from the source. It should be noted that no further discrepancies were noted and that both dosimeters subsequently performed essentially the same.

The amount of radiation each film in the different divisions of the investigation was to receive was calculated and the time of exposure to the unshielded source and the distance from the source was determined for individual films. Appropriate half life formulas were employed to determine the activity of the source on the days it was to be used.

The next operation involved positioning the remote control device on the table and securing it to prevent further movement. Attached to the vertical supporting rod of the apparatus was a rod fastened horizontally by means of a right angle clamp. The vertical height above the table to which the source was to be elevated was indicated by this rod. By extending this rod toward the working area and adjusting the elevation of the rod to which the source would be attached, the ends of the two rods were made to meet. This point of intersection was the position from which all measurements of the distances of the film badges from the source were made. In effect, this is the point at which the unshielded source was subsequently placed.

The films, having been properly numbered for identification purposes, were next positioned at the distances required for the desired exposure. Since slots in the corks had been sawed at slight angles, it was possible by applying slight force to the film badges to nearly align them perpendicular to an imaginary line from the source to their position.

In order that the positions of all films with respect to the cork be the same in the event it be needed for future reference, the matte finished outer covering of the film packet was positioned toward the source and the side of the film badge near the indented mark of the film was positioned not in the slot of the cork.

At this time the laboratory was prepared to receive the shielded source. This involved removal to another room of the remaining inventory of film and taking the necessary precautions of checking all windows to be sure they were closed and locked. The portable lead shield used to blockade the doorway was posted with the appropriate radiation caution sign.

The source was removed form its storage cabinet and brought, still contained in its lead shield, into the laboratory and placed on the ring stand base. Dr. P. S. Helmick, the person authorized by the Atomic Energy Commission to control the use of the radioactive material, performed all necessary moving operations involving the source. Care was taken to place the screw nut assembly of the source assembly directly below the remote control rod. This is necessary because there is enough play in the remote control apparatus that it may extract the source at a small angle from the lead shield. In the event this occurs, the source will not fall precisely into its small cavity in the shield at the conclusion of the experiment. This subsequently necessitates that the investigator approach the source and by directly manipulating the end of the remote control rod opposite the source, to realign the capsule containing the radioactive material and lower it into the cavity of the storage container manually. This naturally exposes the investigator to more radiation than necessary, although the quantity of radiation still remains far below the maximum permissible dosage.

The remote control rod was attached to the screw and nut assembly and the assembly disengaged from the threads of the storage container. The remote control cord was pulled, the source subsequently being removed from the container, and the cord adjusted so the source was at the proper height. Simultaneously with the removal of the source, a count of time began. The source was secured at the desired height by fastening the cord to a massive object, thus preventing any further movement.

In keeping with the policy of limiting the radiation received personally to the minimum possible, the room was evacuated until such time as re-entry to conclude the experiment was necessary. The room was chained and padlocked to prevent unauthorized entry and posted with the proper radiation sign.

The films were promptly removed from the room to minimize the small quantity of radioactivity penetrating the source container after the exposure was completed. The person authorized to control the use of the radioactive material was then notified and arrangements for returning the source to its storage cabinet concluded. If there was to be a delay in removal of the source to storage, the investigator again sealed the room using the chained and padlocked lead shield properly posted with the radiation caution sign.

In every instance except the delayed development division of the investigation, the development of the film badges was performed the same day as the exposure to radiation. Development of the film badges involved three major steps; (1) securing the development variables; (2)

labeling the film for permanent identification and loading the developing tank; and (3) the actual development processes.

Except where varied by experimental design, the temperature of the developing solution, the concentration of the solution, and the time the film was in the solution were kept constant within the capabilities of the measuring instruments used.

The film was developed at the recommended temperature of twenty degrees centigrade. The hot and cold taps of the darkroom were let run until the water from each was at a constant temperature. Using the thermometer selected as the standard for the investigation, the two taps were adjusted until the water reached an indicated temperature of twenty degrees centigrade. A water storage container was filled, keeping a constant check of the temperature of the water coming from the taps. The sink was plugged and filled with the twenty degree water. The latter procedure provided a volume of water of such magnitude as to be considered a constant temperature bath for the time required for development processes. The water storage container was immersed in this bath to maintain it at twenty degrees centigrade.

Using water from the water storage container, the concentrated developer and fixer were diluted, using unless varied by experimental design, the recommended ratios of dilution as stated in the definitions of this report. The developer was immediately poured into the tank and the unit immersed in the constant temperature bath formed by the sink. The fixer was placed in its storage container and also placed in the constant temperature bath.

It should be noted that throughout the investigation, the same thermometer and graduated cylinder were used. Thus any errors due to the instruments were held constant and by nature of the work did not enter into the results in a detrimental manner.

After determining that the tank and developer combination were at the twenty degree centigrade temperature, the room was totally darkened. As each film was removed from its wrapping, a fine ball point pen was used to affix a code number permanently. The film emulsion is pressure sensitive, hence writing on the film with a somewhat sharp object leaves upon development the code number in the form of very dense tracks on the film.

The developing tank used contains as its inner part a threaded reel upon which roll film may be wound. At one point on the edge of the reel are the beginning of the threads. By adjusting the width of the reel, the films were backed into it by holding them in one hand and rotating the reel with the other. This being done in total darkness required the investigator to exercise extreme caution, otherwise one film would be pushed on top of another and both ruined during the development process.

After the film badges were loaded onto the reel, the reel was placed in the tank body which already contained the developer. At the same time a stop watch was started to mark the time. The tank was then sealed light-tight by placing the lid in its proper position and tightening. At this point it was possible to again have the lights on.

As emphasized by Corney, the reaction products of the development process diffuse out of the emulsion layer and, if the films are not subjected to agitation, produce a layer of partially exhausted developer at the film surface.[1] For this reason, constant agitation sufficient to produce turbulent flow of solution about the films was provided during development.

Since the effects of developer exhaustion depend on the average density of developed films, carry-out of developer by processed films, and the manner in which loss of developer is replaced, freshly mixed developer was used with each batch of films processed.

When the development process was completed as indicated by the stopwatch, the tank was inverted permitting the

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[1]*Ibid.*

removal of the developer solution through the light trap drains built into the tank. Upon complete draining of the developer, the tank was placed below a running cold water tap and the film washed for the recommended two minutes. The tank was again drained and the fixing solution introduced through the light traps provided.

The films remained in the fixing solution for a period of ten minutes. At the completion of this process the fixer solution was drained and the tank opened to view the film badges. The films, still contained in the reel, were subjected to washing in running water for a period of one half hour. At completion of the washing cycle the films were removed from the reel and blotted with paper towels to remove any excess water. The film badges were then placed on dry paper towels and permitted to air dry.

Subsequent to the development procedures, the film was subjected to measurements of optical density utilizing the Weston Photographic Analyzer available in the Drake physics department. The meter of the instrument is calibrated in density units, is condensed somewhat as regards markings at the minimum and maximum ends of the scale, and is somewhat expanded in the middle of the scale. To take advantage of the scale expansion, the instrument was adjusted so the zero or starting point would be within the stated expansion.

In the section of the investigation involving the reproducibility of the film, nine density readings were taken of each film in the approximate positions indicated in Figure 1. In the remaining parts of the investigation, the number of readings were reduced to five as indicated also in Figure 1. This action was justified by the ability of each film to give substantially identical density measurements over its entire surface, excepting the extreme edges.

All density measurements were taken in rooms darkened to conditions similar to those normally considered essential for good motion picture projection. The only source of light within the room itself was the densitometer light used to shine through the film and the red meter lights contained within the instrument to provide light with which to read the meter. To avoid variations in the instrument readings caused by line voltage fluctuations, a constant voltage transformer was used in conjunction with the densitometer.

The actual density measurements were carried out by placing the desired portion of the film over the port through which the light is permitted to exist from the lamp housing of the instrument. The photoelectric cell holder was then placed over the light transmitting port, the film being sandwiched then between it and the instrument casing. Care

Figure 1. Approximate positions used for density measurements.

was taken not to place the cell arrangement onto the film with too much force, as this tended to dent the emulsion and yield an erroneous density measurement. The meter was then read and the reading subtracted from the starting reading to determine the density of the film.

In the parts of the experiment where necessary, control films were utilized and the optical density increase in a film due to gamma radiation determined by subtracting the sample's density from the control density.

CHAPTER III

DATA COLLECTION AND ANALYSIS

Data collection and analysis in this research involved investigation of the six characteristics of the film badges which would influence the applicability of this dosimetry method at Drake University. This chapter deals with the data obtained in each of these areas and its significance to the situation under study. The six characteristics are reproducibility, minimum recordable dosage, a calibration curve for the batch of film in use, variation in density with development temperatures and developer concentrations, and the effect of storage of film after exposure and prior to development.

I. REPRODUCIBILITY

To evaluate the reproducibility characteristic of the film involved investigation to determine if a number of samples of the film badges would yield the same density measurements upon being exposed to identical quantities of radiation. It was also desired to note if the film badges would reproduce at several different levels of radiation exposure.

Four groups of five films each were exposed respectively to 95 mr., 24 mr., 5.9 mr., and 2.7 mr. The film groups were placed the proper distances from the source so the desired quantity of radiation would be received. All films were exposed for the same sixty minute period of time. Subsequent to exposure, the films were developed simultaneously in the developing tank under standard conditions.

Upon drying, the films were subjected to density measurements using the densitometer. Nine density measurements were recorded for each film. The nine density measurements were averaged for each film, and the average density plotted against sample number for that level of radiation. This is indicated in Figure 2.

Maximum variation was encountered in the samples exposed to 95 mr., the variation amounting to 0.02 optical density units between the lowest density sample and the highest density sample. Three other samples recorded the same average density and fell midway between the two samples at the upper and lower extremes. All samples exposed to 24 mr. of radiation exhibited the same average density. Four of the samples in the 5.7 mr. group were of the same density, the one other sample varying by 0.01 optical density units. The group exposed to 2.7 mr. recorded the same density for all samples.

The results of this part of the investigation are considered quite satisfactory. The densitometer used is capable, under the conditions specified for its use, of being read to 0.01 optical density units. The variation of two parts in approximately thirty seven and one part in approximately twenty three can be considered as negligible for the purposes of this study. Optical density variations in all the films used in this part of the investigation amounted to four variations in a total of twenty possible. It is the conclusion of the investigator that the film will reproduce to a degree of accuracy acceptable for the requirements of the institution.

II. MINIMUM RECORDABLE DOSAGE

Eastman Kodak Company claims a minimum sensitivity for the Type 2 film of approximately twenty milli-roentgens when exposed to gamma radiation from a radium source.[1] Since the radiation levels students are subjected to at Drake are considerably lower than this figure, it was desired to investigate the minimum dosage the films could record, under recommended conditions of development and under exposure to the Cobalt-60 source.

The investigative method involved exposing films to

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[1]*Radiation Monitoring With Kodak Personal Monitoring Films* (A Pamphlet Prepared by Eastman Kodak Company, Rochester: Eastman Kodak Company, 1959).

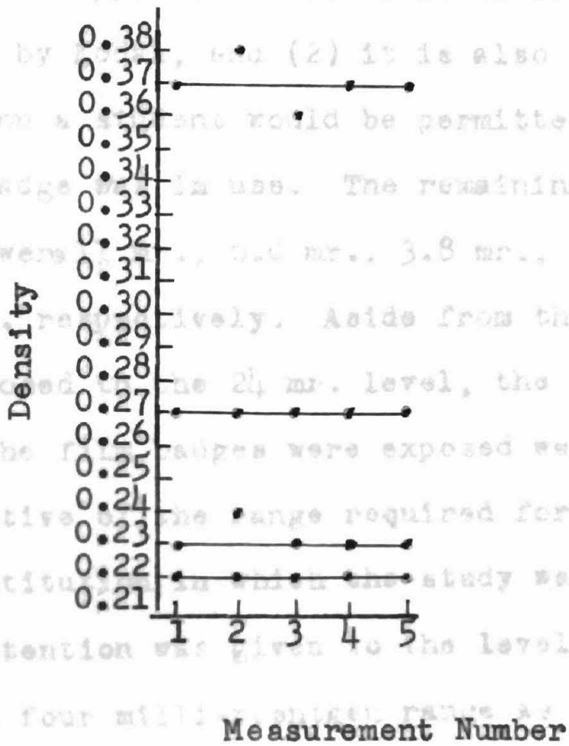

Figure 2. Reproducibility of Kodak Personal Monitoring Film, Type 2.

decreasing amounts of radiation until a point was reached such that the film no longer gave a recordable decrease in density and/or erratic density measurements.

Seven levels of radiation were used in exposing the films. The maximum of 24 mr. was selected for two reasons; (1) it is the approximate lower level of recordable dosage as claimed by Kodak, and (2) it is also a high maximum amount of radiation a student would be permitted to receive while one film badge was in use. The remaining six levels of radiation were 11 mr., 6.0 mr., 3.8 mr., 2.7 mr., 2.0 mr., and 1.5 mr. respectively. Aside from the group of film badges exposed to the 24 mr. level, the levels of radiation to which the film badges were exposed were chosen as being representative of the range required for dosimetry purposes in the institution in which the study was conducted. Special attention was given to the levels of radiation in the one to four milli-roentgen range as this is the quantity most often encountered in the laboratory for which the investigation was designed and the investigator desired at the outset to determine if the film badges were adaptable to this small quantity of radiation.

The exposed films were developed under standard conditions. The results of the films processed under this phase of the investigation indicate that the film is sensitive to approximately three milli-roentgens of the gamma radiation.

When plotted graphically, as illustrated in Figure 4, the curve appears to be essentially linear until a level corresponding to 2.5 mr. is used. For radiation levels lower than this value, the curve rapidly drops off and becomes for all practical purposes horizontal, which indicates the film density of the exposed samples is not significantly different from that of the control films.

In an attempt to determine if the film could record less than the level of radiation indicated by the previous exposure, additional groups of four films were exposed to levels of 2.0 mr., 1.7 mr., 1.4 mr., and 1.2 mr. The films were developed under standard conditions. The resulting densities of the control films developed simultaneously and the densities of the experimental films were not perceptably different.

It is therefore the conclusion of the investigator that the films will record radiation exposures to the Cobalt-60 source as small as three milli-roentgens, but attempts to record smaller received quantities are not feasible. Since in any one week a person may legally accumulate 300 mr. of radiation, a dosimetry device capable of recording a total dosage received of one per cent of that permitted can be deemed as satisfactory for the conditions under investigation.

III. CALIBRATION

In previous and following portions of the investigation, the film badges have been exposed to a known quantity of radiation. Under these circumstances the resulting optical density of the film badges can be directly equated to a specific quantity of radiation received. In use as a dosimetry device it is not possible to know what amount of radiation the badge has received, for it is the function of it in fact to determine this very thing. To equate the net density of a film badge to a specific quantity of radiation, the film used must be calibrated. Since each batch of film received has been subjected to different conditions of processing, storage, handling, and consequently different amounts of background radiation, it is very unlikely that two different inventories of film would respond identically to the same quantities of radiation. Therefore, with the introduction of each new inventory it is necessary to run a calibration test for that batch of film. This involves exposing samples to known and differing quantities of the radiation used and plotting the resulting net densities against exposure in the proper units. The net density is determined by developing along with the exposed films, samples receiving no experimental radiation and having the same historical background as those exposed. Historical background involves the conditions that the controls have been taken from the same batch as processed by the manufacturer and have been stored with the experimental films.

In the investigation under discussion, the calibration curve was desired to run from 60 mr. to 1.5 mr. The upper limit represents the maximum permissible dosage per eight hour working day and is far beyond what is ever intended for a student to receive. The lower limit represents an additional attempt to see if the film was sensitive to this small quantity of radiation since the investigator was now using a different batch of film, having exhausted the previous supply. In addition, more points were desired to be plotted at the lower levels of exposure, as this is the portion of the curve likely to be applicable to the students. Twenty four films, representing eleven different levels of radiation with two films exposed to each level, and two films used as controls, were used in this part of the investigation.

The results of the data obtained, illustrated graphically in Figure 3, gave a calibration curve which for all practical purposes is linear from sixty milli-roentgens to approximately 2.5 milli-roentgens. Below 2.5 mr. the net densities become sporadic and/or zero. The zero value is interpreted as meaning the film did not respond measurably to the received radiation and therefore the density did not change from that represented by the control.

IV. VARIATION OF DEVELOPER TEMPERATURE

As stated by Boucher, it must be noted that a change in developer temperature will cause a resulting optical density change in film.[1] The darkroom of the physics department at Drake University has no provision for temperature control of either water obtained from the mains or for the constant temperature storage of chemicals during use. It was therefore considered essential that the effect of changing developer temperature on the film badge density be considered before a recommendation as to the practicability of this service for Drake could be made.

Samples were exposed to five different levels of radiation, ranging from 3.1 mr. to 50 mr. Six samples were exposed within each level. Subsequent to exposure, the films were divided into groups to be developed at temperatures of 18, 20, and 22 degrees centigrade. Each temperature

[1] Paul E. Boucher, Fundamentals of Photography (New York: D. Van Nostrand Company, Inc., 1955), pp. 115-116,

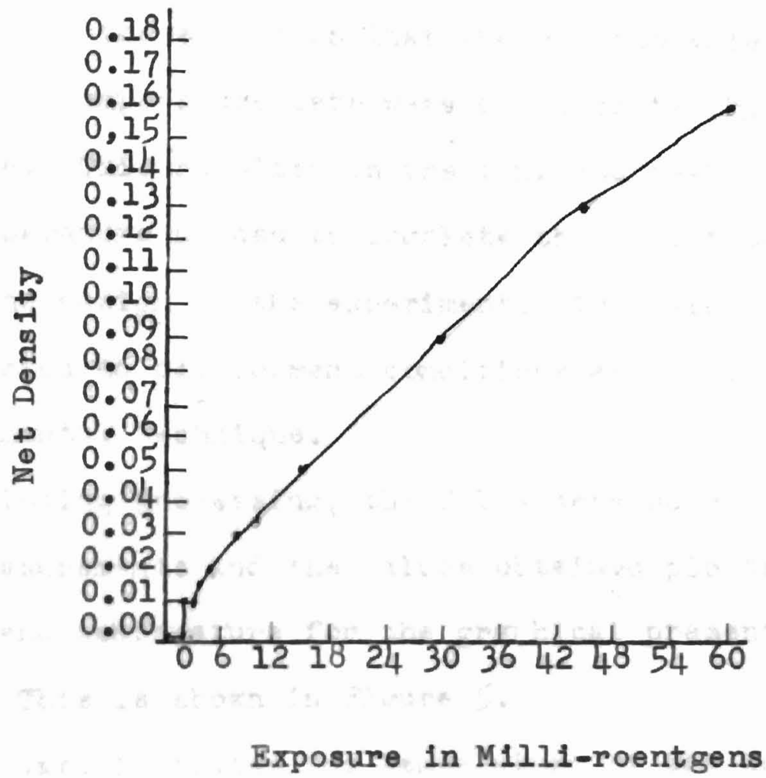

Figure 3. Calibration curve for batch number 20140124455, Kodak Personal Monitoring Film, Type 2.

level contained two films from each of the five levels of exposure.

After the films from a particular temperature were loaded into the film tank, the chemicals were mixed and stored in the same manner as described in the experimental technique with the exception that the storage water and the constant temperature bath were adjusted to the desired temperature. This resulted in the tank and developer being at the temperature needed to complete the conditions set forth in the design of the experiment. The films were then subjected to development conditions as set forth in the experimental technique.

Following processing, the films were subjected to density measurements and the values obtained plotted as densities and temperature for the graphical presentation of the data. This is shown in Figure 5.

The data indicates the temperature of the developer to be of importance to the successful use of film badges as dosimetry devices. If the calibration curve previously determined were considered to be applicable to the films contained in this portion of the investigation, increase in density of the films exposed to 3.1 mr. could lead to an error in the range of approximately four milli-roentgens, which is slightly greater than one hundred per cent error.

For an exposure of fifty milli-roentgens the error would be approximately ten milli-roentgens, an error of about forty per cent. While these totals still remain within the legally acceptable maximums, it is very doubtful that the health of the students should be subjected to such great uncertainties. It is therefore the conclusion of the investigator that the temperature must be maintained at the recommended twenty degrees as indicated by the thermometer used as the temperature indicating device.

V. VARIATION OF DEVELOPER CONCENTRATION

Boucher states that another factor effecting density of developed film is the concentration of the developer solution.[1] In mixing the volume of developer needed to fill the film tank, it is most convenient to use a one liter graduated cylinder to measure the water and a fifty or one hundred milli-liter graduated cylinder to measure the concentrated developer. The ratio needed to mix a volume sufficient to fill the film tank is 96 cc. of concentrated developer to 404 cc. of water. It is fairly easy to measure with sufficient accuracy the concentrated developer using the small graduate. However, due to lighting conditions

[1] *Ibid.*, pp. 130-133.

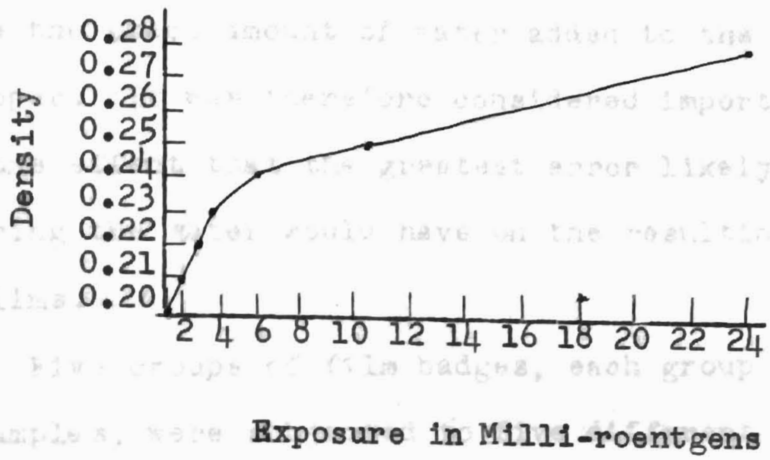

Figure 4. Minimum recordable dosage

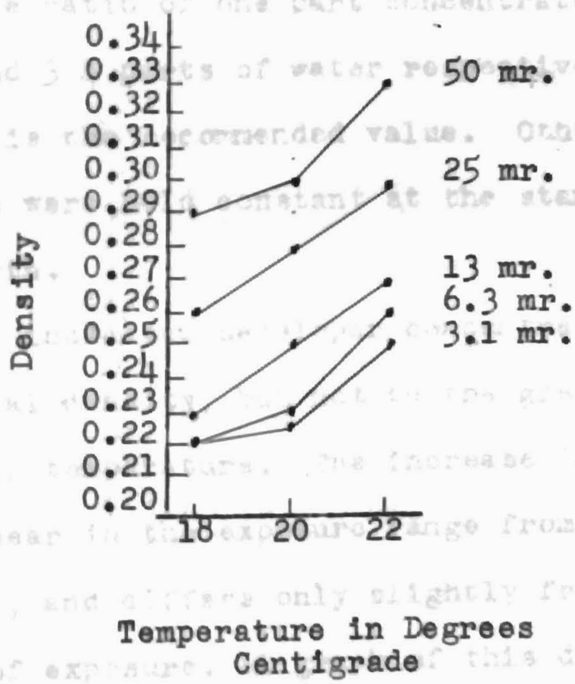

Figure 5. Change in film density resulting from variations in developer temperature.

of the darkroom and other associated errors in filling the graduate, it is very likely that 404 cubic-centimeters will not be the exact amount of water added to the concentrated developer. It was therefore considered important to ascertain the effect that the greatest error likely to occur in measuring the water would have on the resulting densities of the films.

Five groups of film badges, each group containing six samples, were subjected to five different levels of radiation, ranging from 50 mr. to 3.1 mr. Two samples from each group were subjected respectively to development in developer of three different concentrations. The developer was mixed in the ratio of one part concentrated developer to 4.7, 4.2, and 3.4 parts of water respectively. The 1 to 4.2 ratio is the recommended value. Other development conditions were held constant at the standards previously set forth.

The data indicated developer concentration does effect resulting optical density, but not to the great extent as was found for temperature. The increase in density is essentially linear in the exposure range from approximately 3 mr. to 13 mr., and differs only slightly from that in the higher levels of exposure. A graph of this data is illustrated in Figure 6. Since the ratios used represent a

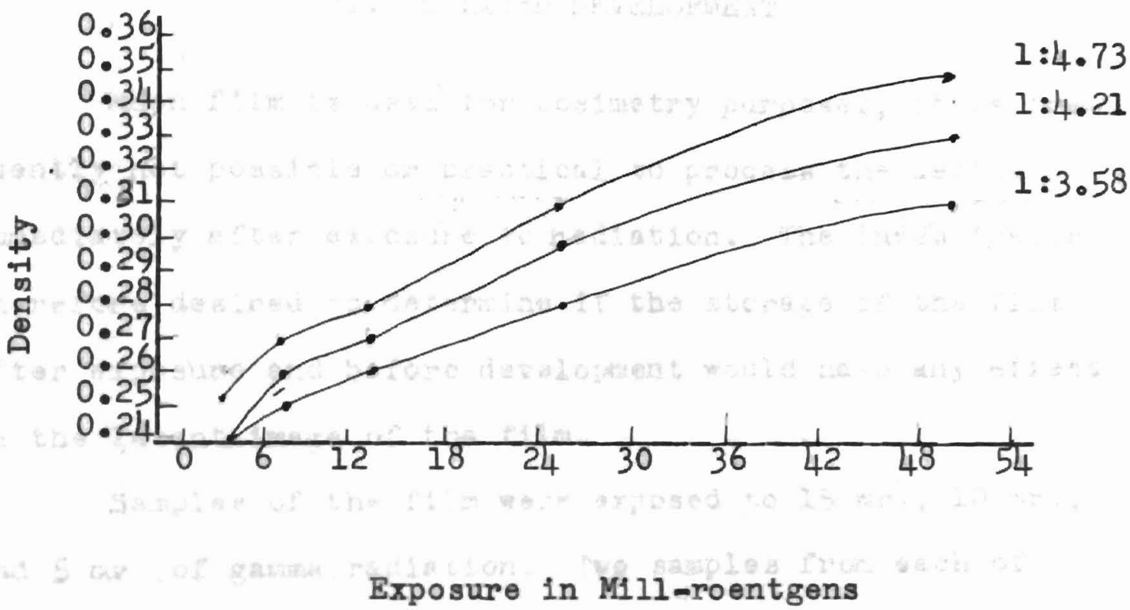

Figure 6. Change in film density resulting from variations in developer concentration.

deviation of 50 cc. from the recommended proportions, extreme care need not be used in mixing the developer, as this is the maximum error in mixing the investigator anticipated would be made by persons processing the film.

VI. DELAYED DEVELOPMENT

When film is used for dosimetry purposes, it is frequently not possible or practical to process the device immediately after exposure to radiation. The investigator therefore desired to determine if the storage of the film after exposure and before development would have any effect on the latent image of the film.

Samples of the film were exposed to 15 mr., 10 mr., and 5 mr. of gamma radiation. Two samples from each of the three radiation levels were processed at intervals of 0, 2, 4, and 8 days after exposure. Also processed simultaneously were two control films with each group. The development process was performed under standard conditions.

The films were subjected to optical density measurements and the results plotted graphically, as is shown in Figure 7. The data indicated that an increase in optical density occurred in the films processed two days after exposure, while those processed at four and eight days remained practically constant, a slight increment in optical density noted. Since the control films processed simultaneously did not indicate this increment in density, the possibility of error in development procedures would seem not to be the causing factor of the increment.

In an attempt to further investigate this second day increment, the experiment was repeated using the same levels of radiation, the same number of film samples, and the same time delay between developments and exposure. Development again was accomplished under standard conditions.

The resulting optical densities when the experiment was repeated are not of the same pattern as those previously encountered. Previously, all but the control films had indicated the increment on the second day. In the repeated portion of the experiment, the films subjected to 15 mr. indicated no increment in optical density until the group held four days was developed. A sharp rise was then noted and a subsequent slight decrease in density for the samples processed at eight days. Figure 8 illustrates this data graphically.

The samples exposed to 10 mr. demonstrate an approximate linear increment in optical density through those developed on the fourth day. The samples processed on the eighth day are essentially the same in density as the samples processed on the fourth day.

The 5 mr. samples yield a curve essentially linear through the entire period of delayed development. The control films remained for all practical purposes constant in optical density.

Consideration of data obtained from the two experiments in delayed development tend to indicate the film reacts in a sporadic manner when development does not immediately follow exposure. Until further investigation of these factors is undertaken, it is advisable to develop all films used immediately after exposure.

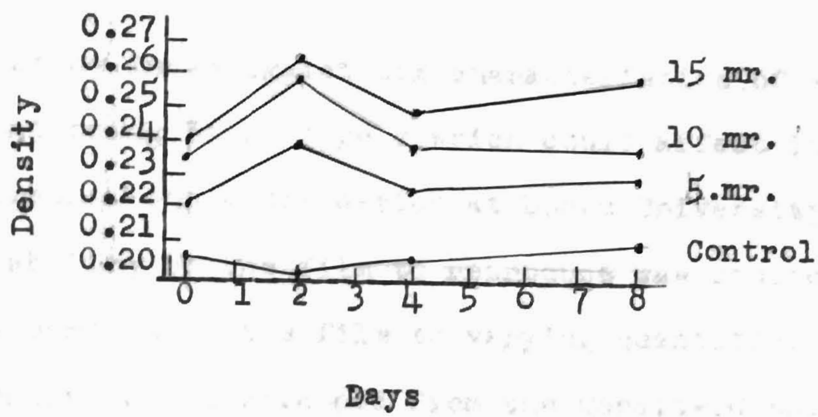

Figure 7. Variations in film density resulting from delayed development, part one.

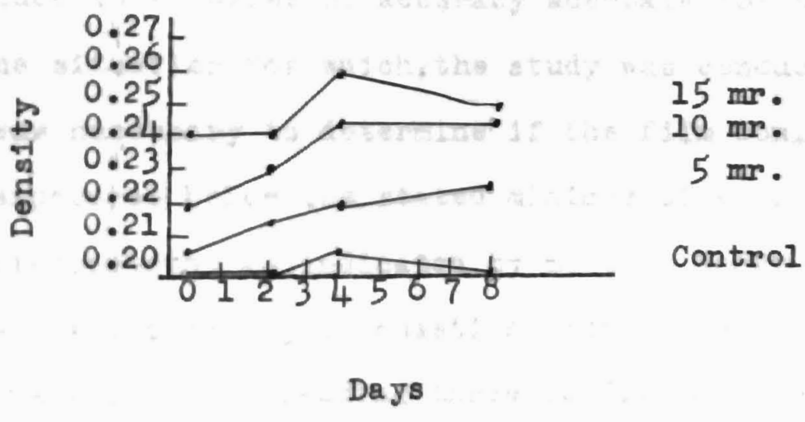

Figure 8. Variations in film density resulting from delayed development, part two.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The study investigated six characteristics of Kodak Personal Monitoring Film, Type 2 which could affect its use as a personal dosimetry device at Drake University.

The ability of the film to reproduce was studied by exposing samples of the film to varying quantities of the gamma radiation as obtained from the Cobalt-60 source used in the investigation. After development, the optical densities of the samples were measured and a graph constructed by plotting sample number and density for each radiation level used. The data indicated that the films will reproduce to a degree of accuracy adequate for the needs of the situation for which the study was conducted.

It was necessary to determine if the film would record radiation exposures below the stated minimum of approximately twenty milli-roentgens as indicated by Eastman Kodak Company, since the laboratory in question exposes personel to amounts usually not exceeding three to five milli-roentgens. The film was exposed to several levels of radiation in decreasing amounts until the film no longer gave recordable decreases in density. The data indicated the minimum recordable dosage using recommended development procedures to be approximately three milli-roentgens. This is considered satisfactory for the situation under study.

The calibration of the film was accomplished by exposing samples of the film to known quantities of radiation. In this particular study the upper limit was sixty milli-roentgens. After development the optical net densities were determined and exposure and net density plotted graphically. A film of the same batch having received an unknown amount of radiation could be processed and its net density compared with the graph. By this method the quantity of radiation received by the film is determined. This was a procedural matter and the results have no bearing on the acceptance or rejection of the service.

The effect of developer temperature on the resulting densities of the films was investigated for three temperatures at five levels of radiation. It was determined that an increase or decrease in developer temperature from the recommended twenty degrees centigrade has a marked effect on the resulting density of the film. It is the conclusion of the investigator that developer temperature must be controlled within the limits of accuracy permitted by an ordinary laboratory type thermometer.

The effects of changing developer concentrations was investigated at the maximum upper and lower limits that might occur in the darkroom. Sample films were exposed to varying amounts of radiation and subjected to development in the three different concentrations of developer solution. The results indicated a slight increment in density for the films developed in the more concentrated solution and a slight decrease in density for those processed in the weaker solution. However, the increment in density with increasing concentration of developer solution was not great enough that more than ordinary care need be exercised in the darkroom mixing procedures.

To determine if holding films after exposure and prior to development would affect the resulting density, films were exposed to varying quantities of radiation and developed at delayed intervals over an eight day period. The results indicated an increment in density on the second day and very little increment for the other days, even though the films were held for a longer period of time. In an attempt to investigate this second occurrence further, the experiment was repeated. The data obtained in the second attempt was more erratic than that previously obtained. The investigator has no theory as to the cause of this. It is the suggestion of the investigator that all films be processed the same day as exposure is accomplished until further investigation into this area can be completed.

The data obtained in the investigation indicated that Kodak Personal Monitoring Film, Type 2 is applicable for use in the nuclear physics laboratory at Drake University as a personal dosimetry device. Normal darkroom procedures can be used with the film with some caution needed in temperature control of the developing solutions.

Further investigation in this area could involve a determination of correction factors for time of development, temperature of developer, and concentration of developer. Additional study is needed in the delayed development area, as the data obtained in this study is not conclusive or even indicative of the cause of the density variations.

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APPENDIX

REPRODUCIBILITY OF KODAK PERSONAL
MONITORING FILM, TYPE 2

Sample Number	Exposure (mr.)	Density* 1	2	3	4	5	6	7	8	9	Av.
1	95	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
2	95	.37	.38	.38	.38	.38	.37	.38	.38	.37	.38
3	95	.37	.37	.37	.37	.37	.36	.36	.36	.36	.36
4	95	.37	.36	.37	.37	.37	.37	.37	.37	.37	.37
5	95	.37	.37	.37	.37	.37	.37	.37	.36	.36	.37
6	6.0	.24	.24	.24	.23	.23	.24	.23	.23	.23	.23
7	6.0	.24	.24	.24	.24	.24	.24	.24	.24	.24	.24
8	6.0	.23	.24	.24	.24	.23	.23	.24	.23	.23	.23
9	6.0	.24	.23	.24	.24	.23	.23	.23	.23	.23	.23
10	6.0	.23	.23	.23	.23	.23	.23	.23	.24	.24	.23
11	2.7	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22
12	2.7	.23	.22	.22	.23	.22	.22	.22	.22	.22	.22
13	2.7	.22	.22	.22	.22	.22	.23	.22	.22	.22	.22
14	2.7	.22	.23	.22	.23	.22	.22	.22	.22	.22	.22
15	2.7	.22	.22	.22	.22	.22	.22	.22	.22	.22	.22
16	24	.27	.27	.27	.27	.27	.26	.26	.27	.27	.27
17	24	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27
18	24	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27
19	24	.27	.26	.27	.27	.27	.26	.26	.27	.27	.27
20	24	.26	.26	.27	.27	.26	.26	.27	.27	.27	.27

*Nine measurements per sample were made and the average computed.

MINIMUM RECORDABLE DOSAGE
PART ONE

Sample Number	Exposure (mr.)	Density* 1	2	3	4	5	Average
21	24	0.28	0.28	0.28	0.28	0.28	0.28
22	24	.28	.28	.28	.28	.28	.28
23	24	.29	.29	.29	.29	.29	.29
24	24	.28	.28	.28	.28	.29	.28
25	11	.25	.25	.25	.25	.25	.25
26	11	.25	.25	.25	.25	.25	.25
27	11	.25	.25	.25	.25	.25	.25
28	11	.25	.25	.26	.25	.25	.25
29	6.0	--	--	--	--	--	--
30	6.0	--	--	--	--	--	--
31	6.0	.24	.24	.24	.24	.24	.24
32	6.0	.24	.25	.24	.24	.24	.24
33	3.8	.23	.23	.23	.23	.23	.23
34	3.8	.23	.23	.23	.23	.23	.23
35	3.8	.22	.23	.22	.22	.23	.22
36	3.8	.23	.23	.23	.23	.22	.23
37	2.7	.22	.22	.22	.22	.22	.22
38	2.7	.22	.22	.22	.22	.22	.22
39	2.7	.22	.23	.22	.22	.22	.22
40	2.7	.23	.23	.23	.23	.23	.23
41	2.0	.21	.21	.21	.21	.21	.21
42	2.0	.21	.21	.21	.21	.20	.21
43	2.0	.20	.20	.20	.20	.20	.20
44	2.0	.20	.20	.20	.20	.20	.20
45	1.5	.20	.20	.20	.20	.20	.20
46	1.5	.20	.20	.20	.20	.20	.20
47	1.5	.21	.20	.20	.20	.20	.20
48	1.5	.20	.21	.21	.21	.21	.21
49	0	.20	.20	.20	.20	.20	.20
50	0	.20	.20	.20	.20	.20	.20

*Five measurements per sample were made and the average computed.

MINIMUM RECORDABLE DOSAGE
PART TWO

Sample Number	Exposure (mr.)	Density* 1	2	3	4	5	Average
51	2.0	0.22	0.22	0.22	0.22	0.22	0.22
52	2.0	.22	.22	.22	.22	.22	.22
53	2.0	.22	.22	.22	.22	.22	.22
54	2.0	.22	.22	.22	.22	.22	.22
55	1.7	.22	.22	.22	.22	.22	.22
56	1.7	.22	.22	.22	.22	.22	.22
57	1.7	.23	.23	.23	.23	.23	.23
58	1.7	.23	.22	.22	.22	.22	.22
59	1.4	.22	.22	.22	.22	.22	.22
60	1.4	.22	.22	.22	.22	.22	.22
61	1.4	.22	.22	.22	.22	.22	.22
62	1.4	.22	.22	.22	.22	.22	.22
63	1.2	.22	.22	.22	.22	.22	.22
64	1.2	.22	.22	.22	.22	.22	.22
65	1.2	.22	.22	.22	.22	.22	.22
66	1.2	.22	.22	.22	.22	.22	.22
67	0	.22	.22	.22	.22	.22	.22
68	0	.22	.22	.22	.22	.22	.22

*Five measurements per sample were made and the average computed.

FILM DENSITY RESULTING FROM VARIATIONS
IN DEVELOPER TEMPERATURE

Sample Number	Exposure (mr.)	Temperature	Density* 1	2	3	4	5	Average
69	50	18°C.	0.29	0.29	0.29	0.29	0.29	0.29
70	50	18	.29	.28	.29	.29	.28	.29
71	50	20	.29	.30	.30	.30	.30	.30
72	50	20	.30	.30	.30	.30	.30	.30
73	50	22	.33	.33	.33	.33	.33	.33
74	50	22	.33	.33	.33	.33	.33	.33
75	25	18	.26	.26	.26	.26	.25	.26
76	25	18	.26	.26	.26	.26	.26	.26
77	25	20	.28	.28	.28	.28	.28	.28
78	25	20	.29	.29	.28	.28	.28	.28
79	25	22	.30	.30	.30	.30	.30	.30
80	25	22	.30	.30	.30	.30	.30	.30
81	13	18	.22	.23	.23	.23	.22	.23
82	13	18	.23	.23	.23	.23	.23	.23
83	13	20	.25	.25	.25	.25	.25	.25
84	13	20	.25	.25	.25	.25	.25	.25
85	13	22	.27	.27	.27	.27	.27	.27
86	13	22	.28	.27	.27	.27	.27	.27
87	6.3	18	.22	.22	.22	.22	.21	.22
88	6.3	18	.22	.22	.22	.22	.22	.22
89	6.3	20	.23	.23	.24	.23	.23	.23
90	6.3	20	.23	.23	.24	.24	.24	.24
91	6.3	22	.26	.26	.26	.26	.26	.26
92	6.3	22	.26	.26	.26	.26	.26	.26
93	3.1	18	.22	.22	.22	.22	.22	.22
94	3.1	18	.22	.22	.22	.22	.22	.22
95	3.1	20	.23	.23	.24	.23	.24	.23
96	3.1	20	.23	.23	.23	.23	.23	.23
97	3.1	22	.26	.25	.26	.25	.26	.26
98	3.1	22	.25	.25	.25	.25	.26	.25

*Five measurements per sample were made and the average computed.

FILM DENSITY RESULTING FROM VARIATIONS IN DEVELOPER CONCENTRATION*

Sample Number	Exposure (mr.)	c.c. of water	Density** 1	2	3	4	5	Average
99	50	354	0.35	0.35	0.36	0.36	0.36	0.36
100	50	354	.35	.36	.36	.36	.36	.36
101	50	404	.34	.34	.34	.33	.33	.34
102	50	404	.33	.33	.33	.33	.33	.33
103	50	454	.31	.31	.31	.31	.31	.31
104	50	454	.31	.31	.32	.32	.31	.31
105	25	354	.31	.31	.31	.31	.31	.31
106	25	354	.31	.31	.31	.31	.31	.31
107	25	404	.30	.30	.30	.30	.30	.30
108	25	404	.30	.30	.30	.30	.30	.30
109	25	454	.28	.28	.28	.28	.28	.28
110	25	454	.28	.28	.28	.28	.28	.28
111	13	354	.29	.28	.28	.28	.28	.28
112	13	354	.29	.28	.28	.28	.28	.28
113	13	404	.27	.27	.28	.27	.27	.27
114	13	404	.27	.27	.27	.27	.27	.27
115	13	454	.26	.26	.26	.26	.26	.26
116	13	454	.26	.26	.26	.26	.26	.26
117	6.3	354	.27	.27	.27	.27	.27	.27
118	6.3	354	.27	.27	.27	.27	.27	.27
119	6.3	404	.26	.26	.27	.26	.26	.26
120	6.3	404	.26	.26	.26	.26	.26	.26
121	6.3	454	.25	.25	.25	.25	.25	.25
122	6.3	454	.25	.26	.25	.25	.25	.25
123	3.1	354	.25	.26	.25	.25	.25	.25
124	3.1	354	.26	.25	.25	.25	.25	.25
125	3.1	404	.24	.24	.24	.24	.24	.24
126	3.1	404	.24	.24	.24	.24	.24	.24
127	3.1	454	.24	.24	.24	.24	.24	.24
128	3.1	454	.24	.24	.24	.24	.24	.24

*The stated quantity of water was in all instances mixed with 96 cc. of concentrated developer.

**Five measurements per sample were made and the average computed.

CALIBRATION OF BATCH NUMBER 2014012455

Sample Number	Exposure (mr.)	Density* 1	2	3	4	5	Average
129	60	0.37	0.38	0.38	0.38	0.38	0.38
130	60	.38	.38	.38	.38	.38	.38
131	45	.34	.35	.35	.35	.35	.35
132	45	.35	.35	.35	.35	.35	.35
133	30	.31	.30	.31	.31	.31	.31
134	30	.30	.31	.31	.30	.31	.31
135	15	.27	.27	.27	.27	.27	.27
136	15	.27	.27	.27	.27	.28	.27
137	10	.25	.25	.25	.25	.25	.25
138	10	.26	.26	.26	.26	.26	.26
139	7.5	.25	.25	.25	.25	.25	.25
140	7.5	.25	.25	.25	.25	.25	.25
141	5	.24	.24	.24	.24	.24	.24
142	5	.24	.24	.25	.24	.24	.24
143	3	.23	.23	.24	.24	.24	.24
144	3	.23	.23	.23	.24	.24	.23
145	2.5	.24	.23	.23	.23	.24	.23
146	2.5	.24	.23	.23	.24	.23	.23
147	2	.23	.23	.23	.23	.23	.23
148	2	.23	.22	.23	.23	.23	.23
149	1.5	.22	.22	.22	.22	.22	.22
150	1.5	.22	.22	.22	.22	.22	.22
151	0	.22	.22	.22	.22	.22	.22
152	0	.22	.22	.22	.22	.22	.22

*Five measurements per sample were made and the average computed.

VARIATIONS IN FILM DENSITY RESULTING FROM DELAYED DEVELOPMENT, PART ONE

Sample Number	Expo-sure (mr.)	Time Delay	Density* 1	2	3	4	5	Average
153	15	0 day	0.24	0.24	0.24	0.24	0.24	0.24
154	15	0	.24	.24	.24	.24	.24	.24
155	15	2	.26	.26	.28	.27	.26	.27
156	15	2	.26	.26	.26	.26	.26	.26
157	15	4	.25	.25	.25	.25	.25	.25
158	15	4	.25	.25	.25	.25	.25	.25
159	15	8	.26	.26	.26	.26	.26	.26
160	15	8	.26	.26	.26	.26	.26	.26
161	10	0	.23	.23	.23	.23	.23	.23
162	10	0	.24	.24	.24	.24	.24	.24
163	10	2	.26	.26	.26	.26	.26	.26
164	10	2	.26	.26	.26	.26	.26	.26
165	10	4	.24	.24	.24	.24	.24	.24
166	10	4	.24	.24	.24	.24	.23	.24
167	10	8	.24	.24	.24	.24	.24	.24
168	10	8	.24	.24	.24	.24	.24	.24
169	5	0	.22	.22	.22	.22	.22	.22
170	5	0	.22	.22	.22	.22	.22	.22
171	5	2	.24	.24	.24	.24	.24	.24
172	5	2	.24	.24	.24	.24	.24	.24
173	5	4	.22	.22	.22	.22	.22	.22
174	5	4	.23	.23	.23	.23	.23	.23
175	5	8	.23	.24	.23	.23	.23	.23
176	5	8	.23	.23	.23	.23	.23	.23
177	0	0	.21	.22	.21	.21	.21	.21
178	0	0	.20	.20	.20	.21	.21	.20
179	0	2	.20	.20	.20	.21	.20	.20
180	0	2	.21	.21	.20	.20	.20	.20
181	0	4	.21	.20	.21	.20	.20	.20
182	0	4	.21	.21	.21	.21	.21	.21
183	0	8	.21	.21	.21	.21	.21	.21
184	0	8	.21	.21	.21	.21	.21	.21

*Five measurements per sample were made and the average computed.

VARIATIONS IN FILM DENSITY RESULTING FROM DELAYED DEVELOPMENT, PART TWO

Sample Number	Exposure (mr.)	Time Delay	Density* 1	2	3	4	5	Average
185	15	0 day	0.24	0.24	0.24	0.24	0.24	0.24
186	15	0	.23	.24	.23	.24	.24	.24
187	15	2	.24	.24	.24	.24	.24	.24
188	15	2	.24	.24	.24	.24	.24	.24
189	15	4	.26	.26	.26	.26	.26	.26
190	15	4	.26	.26	.26	.26	.26	.26
191	15	8	.25	.25	.25	.25	.25	.25
192	15	8	.25	.26	.25	.25	.25	.25
193	10	0	.22	.22	.22	.22	.22	.22
194	10	0	.22	.22	.22	.22	.22	.22
195	10	2	.23	.23	.23	.23	.23	.23
196	10	2	.23	.23	.23	.23	.23	.23
197	10	4	.24	.24	.24	.24	.24	.24
198	10	4	.24	.25	.24	.25	.24	.25
199	10	8	.25	.25	.25	.25	.25	.25
200	10	8	.24	.24	.24	.24	.24	.24
201	5	0	.20	.20	.20	.20	.20	.20
202	5	0	.20	.21	.21	.21	.21	.21
203	5	2	.22	.22	.21	.21	.21	.21
204	5	2	.21	.22	.21	.22	.22	.22
205	5	4	.22	.22	.22	.22	.22	.22
206	5	4	.22	.22	.22	.22	.22	.22
207	0	0	.19	.19	.20	.20	.20	.20
208	0	0	.20	.20	.20	.20	.20	.20
209	0	2	.20	.20	.20	.20	.20	.20
210	0	2	.20	.20	.20	.20	.20	.20
211	0	4	.21	.21	.21	.21	.21	.21
212	0	4.	.21	.20	.20	.20	.20	.20
213	0	8	.20	.20	.20	.20	.20	.20
214	0	8	.20	.20	.20	.20	.20	.20
215	5	8	.22	.22	.22	.22	.22	.22
216	5	8	.23	.22	.23	.23	.23	.23

*Five measurements per sample were made and the average computed.